

EFFECT ON PERFORMANCE AND EXHAUST EMISSION USING LEMONGRASS BIODIESEL AS FUEL ON VCR DIRECT INJECTION DIESEL ENGINE

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ABSTRACT

This paper aims to investigate the performance of a four-stroke single cylinder variable compression ratio diesel engine using blend of lemongrass biodiesel (LGBD) as fuel. Initially, the biodiesel produced from lemongrass oil by transesterification process and can be used as an alternative fuel for diesel engine. "The experiment was carried out in a variable compression ratio diesel engine using LBD20 (20% lemongrass biodiesel + 80% Diesel by v/v basis) to study the performance parameters like brake thermal efficiency (BTE) and brake-specific fuel consumption (BSFC) and exhaust gas emissions like Carbon monoxide (CO), hydrocarbon (HC), oxides of nitrogen (NOx) and smoke opacity emissions were measured with different compression ratios like 16.5:1, 17.5:1, 19:1 and 20:1 at different loads and compared with diesel fuel". "The results revealed that the maximum brake thermal efficiency obtained is about 31.02% for LGBD20 at CR20, which is higher than that of diesel (31.8%). The exhaust emissions CO and HC were reduced by 36% and 24% for LGBD20 mixture of biodiesel when compared to diesel. However, there was increase in NOx by 28% compared to the diesel fuel".

KEYWORDS: Lemongrass Biodiesel, Diesel Engine, Performance, Emission & Compression Ratio

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1. INTRODUCTION

"Compression Ignition engines played a major role in the automotive, power generation and agriculture sectors due to its less fuel consumption and lower operating cost when compared to petrol engines. Diesel engine emits lower carbon monoxide (CO) and hydrocarbon (HC) emissions than a gasoline engine and emits more amount of particulate matter (PM) and oxides of nitrogen (NOx) emissions. Increase in number of automotive vehicles for transportation, increase in cost of petroleum fuels, decrease in trend of petroleum reserves and stringent emission norms have resulted to search alternate fuels for internal combustion engines (IC) such as biomass and biodiesel."^{1,2} "Country like India is desirous to produce different biodiesel from non-edible oil sources like neem, mahua, punnai trees, etc., which can be cultivated in wasteland of the country."³ "The use of biodiesel in diesel engine can reduce the exhaust gas emissions such as carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) emissions".⁴ "Vegetable oil is a very promising alternative fuel to diesel engine since they are non-toxic, biodegradable and renewable in nature and has the properties similar to diesel fuel. Many researchers have attempted to use the vegetable oil as fuel in diesel engines. They reported that the engine produced higher exhaust gas emissions except NOx emissions with slightly lower brake thermal efficiency"⁵⁻⁷.

“Researchers have tried to reduce the exhaust gas emissions by adopting different methods like blending, preheating and converting of vegetable oil into biodiesel by transesterification process. Biodiesel produced from non-edible oils like Jatropha, Karanja and Mahua are some of the popular biodiesels that are currently being considered as alternative to diesel fuel”.⁸⁻¹⁰ “These are clean burning, renewable, non-toxic, biodegradable and environmentally friendly transportation fuels that can be used in neat form or blended with petroleum used in diesel engines”.¹¹ “These biodiesels used in diesel engine produced slightly higher oxides of nitrogen (1–6%) than the diesel fuels but it can be reduced with the use of blended diesel fuel. It is found that the lower concentrations of biodiesel blends improve the thermal efficiency”.^{12,13} Ramadhas *et al.*¹⁴ have done experiments on the performance of a diesel engine using different blends of rubber seed oil, methyl esters (RSOME). It is found that 10% RSOME blend gave better performance and low emission levels at full load conditions.

“Many researchers reported that diesel engines have a negative effect on environment, while using biodiesel as fuel for diesel engine. Some innovative technologies are developed to overcome these problems. Modifications are required in the existing engine designs, such as injection timing, fuel injection pressure and compression ratio to achieve considerable effects on the performance and emissions of diesel engines running on biodiesel and its blends”.^{15, 16} Akash Deep *et al.*¹⁷ have examined the engine performance and emissions using 20% castor oil methyl ester blends with varying IT and IP. The CO and HC were decreased for COME blends with an increase in IP compared to the original IT of 23°BTDC and IP of 200bar. The NO_x was decreased favorably and the smoke level was increased at retarded IT of 21°BTDC at IP of 300bar with the penalty of decrease in overall engine performance. Mohan *et al.* (2014) have examined the overall engine characteristics with Mahua biodiesel blend with different IPs and ITs. The 20% Mahua biodiesel blend with increase in IP (275bar) and IT (21°BTDC) could meet the Euro V emission regulation.

Senthil Kumar, *et al.*¹⁸ evaluated the performance of a diesel engine with rubber seed oil-biodiesel blend with the effects of IP like 200bar, 220bar, 240bar and 260bar. It is found that the BSFC and NO_x emissions were increased together with a reduction in soot, HC and CO emissions as the increase in injection pressures”. Arunprasad and Balusamy¹⁹ “studied the influence of injection pressure and injection timing on the performance and emission characteristics of diesel engines by using mixed biodiesel blends. The results revealed that the BTE was increased by 2.4% with an increase in IP and 1.5% with an increase in the IT for full load, but it is lower than diesel. There is a reduction of HC, CO and smoke emissions for 230bar IP and at 27° bTDC IT and significant increase in NO_x and CO₂ emissions by increasing the IP and IT”.

Muralidharan *et al.*²⁰ investigated “the use of 40% waste cooking oil blend in diesel engine and reported that the BTE is found to be increased when compared to that of standard diesel fuel at higher compression ratios. It is also reported that B40 blends gave higher cylinder pressure and lower heat release rate at high compression ratio due to longer ignition delay when compared with diesel Jindal *et al.*”²¹ “studied the effects of compression ratio and fuel injection pressure on the performance of a diesel engine using Jatropha methyl ester as fuel. The highest performance was achieved at 250-bar fuel injection pressure and compression ratio of 18, at which BSFC improved by 10% and BTE improved by 8.9%. It is found that there is an increase in HC emissions and decreased smoke and CO emissions with increase in compression ratios”. Raheman and Ghadge²² examined the performance of diesel engine using Mahua biodiesel and its blend with No. 2 diesel at varying compression ratio, and fuel injection timing. It is found that the BSFC and exhaust gas temperature were increased, whereas BTE was decreased with increase in the biodiesel blends for all compression ratios and injection timings. It is concluded that 20% biodiesel blend could be safely used in diesel engine.

Gumus²³ have tested the various hazelnut biodiesel blends in diesel engine with various injection timings, compression ratios and injection pressures. “It is reported that 20% biodiesel blend gave better performance with the 20:1 CR, 25°bTDC IT and 200 bar IP at full load. Decrease in cylinder pressure and rate of pressure rise were observed with increase in biodiesel blends”. Sivaramakrishnan²⁴ tested the VCR engine performance and emission characteristics at different blends of Karanja biodiesel. “The BTE of B25 was increased by 5% at CR18 as compared to diesel. The Karanja oil methyl ester blends showed higher cylinder pressure at high compression ratio 18:1 due to its longer ignition delay as compared to diesel”.

Bhaskar *et al.*²⁵ have tested the performance, combustion and emission characteristics of diesel engine using biodiesel–biogas as dual fuel and variable CR. There is an increase in BTE and decrease in CO and HC emissions and increase in NOx emissions were obtained for dual fuel mode at CR18:1 as compared to diesel. S. Prakash *et al.*²⁶ tested the performance and emission characteristics of an automobile engine fueled with fish oil methyl ester to reduce environmental pollution. From the literature, it is found that no research work is available with lemongrass biodiesel with various compression ratios. Hence, the aim of the research work is to test the diesel engine combustion, performance and emission behaviors using diesel and 20% lemongrass biodiesel–diesel blend (LGBD20) with different CRs and the results are compared with the diesel fuel.

2. MATERIAL AND METHODS

2.1 Lemongrass Oil Biodiesel

Table 1: Comparison of Fuel Properties

Properties	ASTM Standard	Diesel	LGBD
Density (kg/m ³)	D4052	840	830
K Viscosity @ 40°C (cSt)	D445	3.2	4.34
Specific gravity	D1298	0.83	0.87
Calorific value (MJ/kg)	D240	43	38.79
Flash point (°C)	D93	55	50
Fire point (°C)	D93	63	58
Cetane Number	D976	48	64
Oxygen (%) by wt	D943	-	12

2.2 Test Engine Set up and Test Procedure

In this research work, the test was conducted in a variable compression ratio with multi fuel capability diesel engine and is coupled with Eddy current dynamometer. Table 2 shows the specifications of the test engine. A separate fuel tank was used to store the diesel and biodiesel blends. A burette and a stopwatch method is used to measure the fuel flow fed into the engine in each load. Test was conducted with all the test fuels for various loads, starting from no load to full load condition in the steps of 25%. Figure 1 shows the schematic of test engine. At each load, “the fuel flow rate and the various constituents of exhaust gases, such as carbon monoxide, hydrocarbon, nitrogen oxides and carbon dioxide were measured by AVL-444 gas analyzer. Smoke opacity was measured by using AVL-437C smoke meter. The exhaust gases like HC, CO, CO₂ are measured by the infrared measurement and other constituent NO is measured by photochemical sensor

Table 3: The Accuracies of the Measurement

Measurements	Accuracy	Uncertainty (%)
Engine speed	± 2 rpm	± 0.2
Temperatures	$\pm 1^{\circ}\text{C}$	± 0.1
Carbon monoxide	$\pm 0.01\%$	± 0.1
Hydrocarbon	± 2 ppm	± 0.2
Nitrogen oxide	± 5 ppm	± 0.1
Burette fuel measurement	± 2 cc	± 1.5
Crank angle encoder	$\pm 0.5^{\circ}$ CA	± 0.2
Load	± 0.1 kg	± 0.1

3. RESULTS AND DISCUSSIONS

“The experiments were conducted in a diesel engine standard compression ratio, injection pressure and injection timing at the rated speed of 1500 rpm. All readings were taken only after the engine attained stable operation. The engine output was varied from no load to full load in steps of 25%, 50%, 75% and 100% in the normal operation of the engine. Initially, the engine was operated with diesel and LGBD20 to obtain the reference data at different loads. Further, the experiments were conducted with different compression ratios like CR16, CR19 and CR20 at different loads. At each load, the fuel flow rate, air flow rate, exhaust gas temperature, emissions of carbon monoxide, hydrocarbon and oxides of nitrogen and smoke opacity readings were taken and recorded for further analysis and the results were compared with diesel and LGBD20 at standard compression ratio CR17.5 at full load”.

3.1 Performance Analysis

3.1.1 Brake Thermal Efficiency

Figure 2 shows the brake thermal efficiency variations with respect to brake power for diesel and lemongrass biodiesel blend at various compression ratios. “The BTE of LGBD20 is 4% lower than diesel at full load condition at standard CR 17.5. The BTE obtained for diesel and LGBD20 at full load is 31.7% and 30.4%, respectively. It is evident that from the graph, the BTE of LGBD20 increases with increase in compression ratio at all loads and for LGBD20 with lower CR16 exhibits lower BTE than standard compression ratio CR17.5. For LGBD20, BTE is increased by 3.3% and 1.5% for CR19 and CR20 and it is decreased by 6.2% at full load when compared to LGBD20 at CR17.5”.

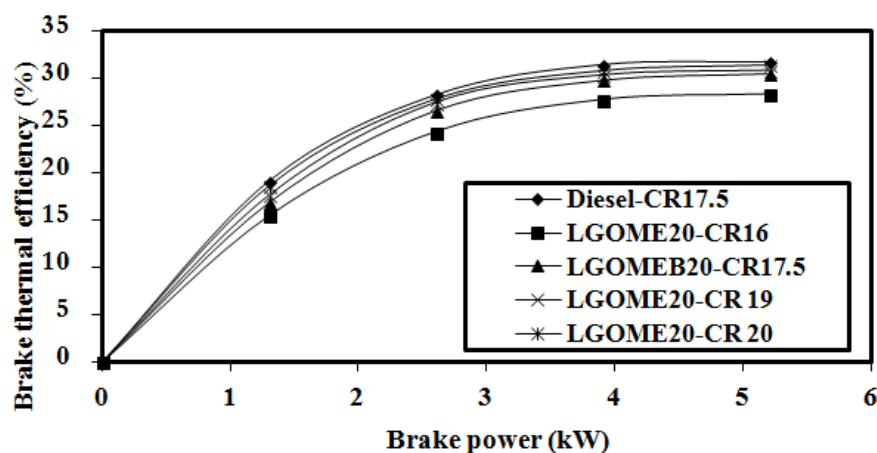


Figure 2: Brake Thermal Efficiency Variations with BP.

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standard CR 17.5. The BTE obtained for diesel and LGBD20 at full load is 31.7% and 30.4%, respectively. It is evident that from the graph, the BTE of LGBD20 increases with increase in compression ratio at all loads and LGBD20 with lower CR16 exhibits lower BTE than standard compression ratio CR17.5. For LGBD20, BTE is increased by 3.3% and 1.5% for CR19 and CR20 and it is decreased by 6.2% at full load when compared to LGBD20 at CR17.5. The increase in BTE for the increase in CR may be due to increase in pressure and temperature during compression process, and the high energy content of LGBD20 (42164kJ/kg) which leads to better combustion and thus increases the BTE at full load. The decrease in BTE for LGBD20 at CR16 may be due to inferior combustion of the low temperature raised during compression process. The BTE of LGBD20 at CR16, CR19 and CR20 is 28.3%, 30.8% and 31.2%, respectively at full load. A similar trend of BTE curve was reported by the researchers Sivaramakrishnan (2018)".

3.1.2 Brake-Specific Fuel Consumption

Figure 3 represents the variation of brake-specific fuel consumption for diesel and LGBD20 at various compression ratios. For LGBD20 with all the compression ratios, the BSFC increases while comparing with diesel fuel.

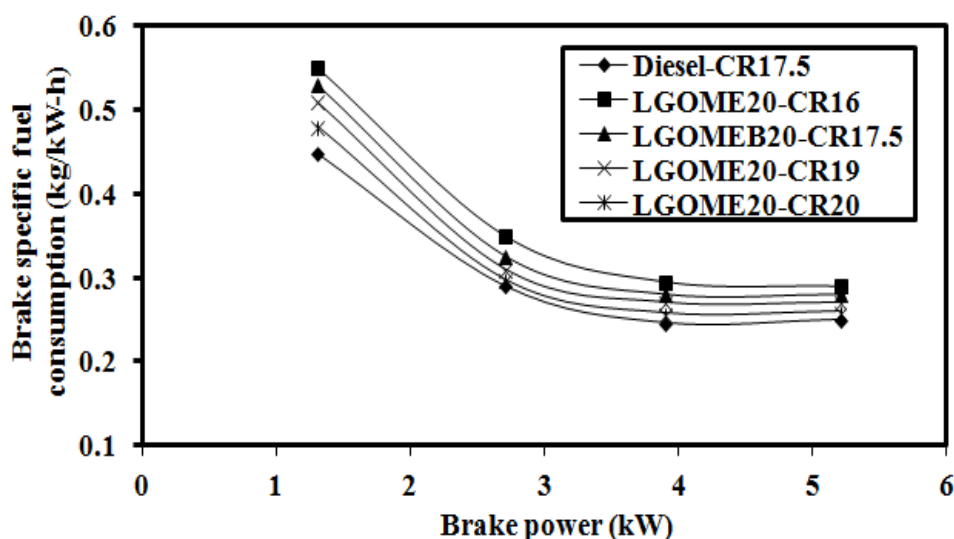


Figure 3: BSFC Variations with BP.

For LGBD20, BSFC is increased by 16% at full load when compared to diesel. This may be attributed to inferior combustion of biodiesel due to its lower calorific value. The BSFC obtained for diesel and LGBD20 at standard CR17.5 is 0.25 and 0.28 kg/kW h, respectively. From the graph for LGBD20 at CR19 and CR20, the BSFC was decreased by 3.5% and 7.1%, respectively. This is because of better combustion of biodiesel, burnt completely at higher combustion temperature developed during higher compression ratios. The BSFC obtained for LGBD20 at CR16, CR19 and CR20 is 0.29, 0.27 and 0.26 kg/kW-h respectively at full load. A similar trend of BSFC curve was reported by the researchers Sivaramakrishnan (2018).

3.1.3 Exhaust Gas Temperature

"The variation of exhaust gas temperature for diesel and LGBD20 at different compression ratios are illustrated in Figure 4. It is known from figure that when the engine load increases, the EGT increases because of more energy released from the fuel and more amount of heat is generated when the higher mass of fuel is being injected at higher loads during the combustion process (Heywood, 1988)".

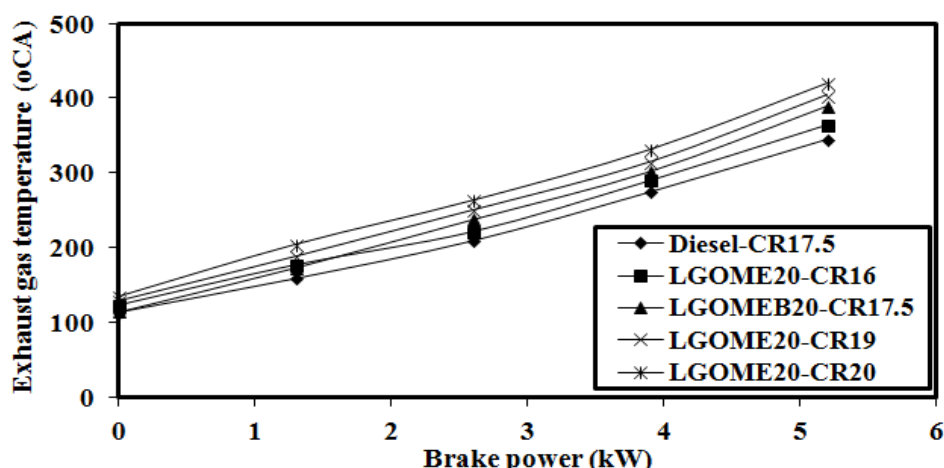


Figure 4: Exhaust Gas Temperature Variations with BP.

It is observed that the exhaust temperature of diesel is lower than LGBD20 at all the loads. It is evident from the graph that the exhaust gas temperature of LGBD20 increases with an increase in compression ratios. It is seen that the EGT of LGBD20 at CR16, CR17.5, CR19 and CR20 produced 13%, 17% and 22%, respectively, higher than diesel fuel at full load condition. This may be attributed to the breaking of molecular bonding, which leads to the rise of exhaust gas temperature. The maximum EGT was measured for diesel and LGBD20 at CR16, CR17.5, CR19 and CR20 as 345°C, 364°C, 389°C, 404°C and 421°C, respectively.

3.2 Emission Analysis

3.2.1 Carbon Monoxide Emission (CO)

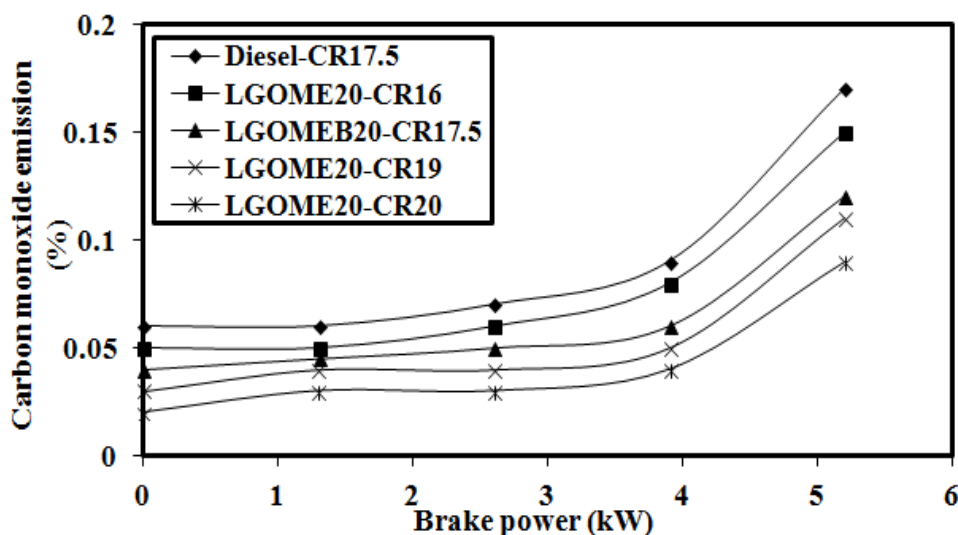


Figure 5: Carbon Monoxide Variations with BP.

“The variations of carbon monoxide emission with respect to brake power for diesel and LGBD20 at different compression ratios are depicted in Figure 5. It is seen that CO emission for LGBD20 is lower than diesel fuel. The CO emission obtained for diesel and LGBD20 is 0.13% and 0.12% at full load. This may be attributed to more oxygen molecule present in the biodiesel, which leads to more oxidation that takes place during combustion of biodiesel blend. Further, the CO emission decreases with an increase in compression ratios at all loads. The CO emission of LGBD20 at CR16, CR17.5, CR19 and CR20 is increased by 12%, 29%, 36% and 47%, respectively, than diesel fuel at full load

conditions. This could be due to the excess oxygen in biodiesel and higher combustion temperature at higher compression ratios and leads to decrease in CO emissions. The CO emission measured for LGBD20 at CR16, CR17.5, CR19 and CR20 is 0.15%, 12%, 0.11% and 0.09%, respectively, at full load. A similar trend of CO curve was reported by the researchers Sivaramakrishnan (2018)".

3.2.2 Hydrocarbon Emission (HC)

"The variation of hydrocarbon emission with respect to brake power for diesel and LGBD20 at different compression ratios are represented in Figure 6. Hydrocarbon emissions are composed of un burnt fuels as a result of the flame quenching on low temperature of the cylinder wall. The flame speed may be too low at lean mixtures for combustion to be completed during the power stroke or combustion may not occur, and these conditions cause high hydrocarbon emissions. It is found that the HC emission for LGBD20 is higher than diesel at standard compression ratio of 17.5:1".

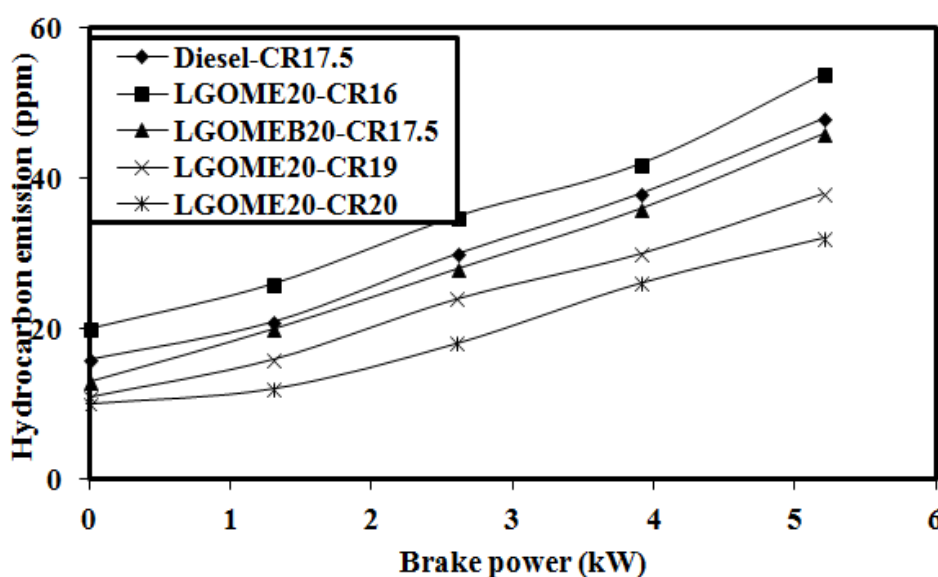


Figure 6: Hydrocarbon Variations with BP.

"The HC emission is obtained for diesel and LGBD20 at CR17.5 is 57 ppm and 52 ppm, respectively, at full load. Further, the HC emission of LGBD20 was decreased by increase in compression ratios. The HC emission is obtained for LGBD20 at CR16, CR19 and CR20 is 64 ppm, 38 ppm and 32 ppm, respectively, at full load. The HC emission was decreased by 21% and 33% for CR19 and CR20, respectively, when compared with diesel fuel. This decrease in HC emission for LGBD20 at higher compression ratio could be due to the shorter ignition delay by increase in cylinder air temperature during the compression process, which leads to more oxidation of biodiesel, which leads to lower HC emissions. The results of HC emissions are in accordance with the researchers Jindal *et al.* (2010)".

3.2.3 Oxides of Nitrogen Emission (NOx)

Figure 7 shows "the variation of NOx emissions of LGBD20 and diesel against brake power at different compression ratios. Generally, oxides of nitrogen generated due to high temperatures (>2,000K) during the combustion process in the combustion chamber. It is noted from the figure that LGBD20 blend emits high NOx emission as compared to diesel. The NOx emission obtained for diesel and LGBD20 is 1950 ppm and 2080 ppm, respectively, at full load".

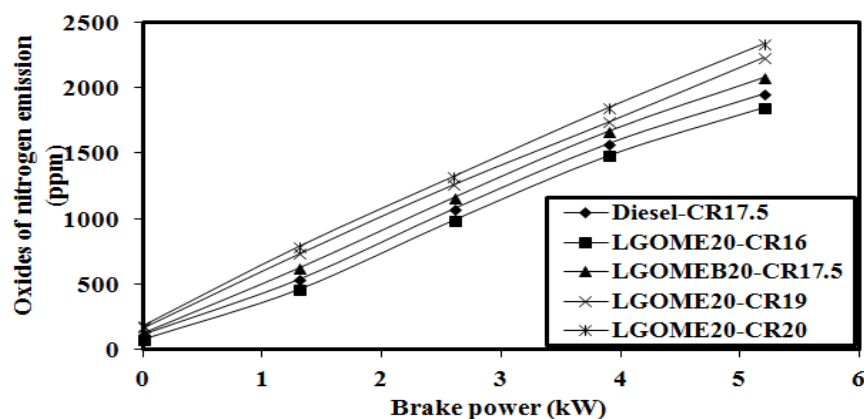


Figure 7: NOx Emission Variations with BP.

“The NOx emissions are increased with an increase in compression ratios of biodiesel blend LGBD20 due to the increase in compression temperature with an increase in compression ratios. The NOx emissions are increased for LGBD20 with CR19 and CR20 by 14.5% and 20%, respectively, when compared with diesel. It may be attributed to higher blend rate of heat release, and excess oxygen present in the biodiesel blend promotes more oxidation, which leads to higher combustion temperatures, but the NOx emission of LGBD20 at CR16 decreased due to its low temperature raised by the low compression ratio of 16:1. At full load, the NOx emission measured for LGBD20 at CR16, CR19 and CR20 is 1850 ppm, 2230 ppm and 2340 ppm, respectively. The results of NOx emissions are in accordance with the researchers, Jindal *et al.* (2010)”.

3.2.4 Smoke Opacity

Figure 8 shows “the variation of smoke emissions against brake power for diesel and LGBD20 at different compression ratios. It can be observed that smoke emission is lower for LGBD20 at full load compared to diesel fuel due to excess oxygen molecule present in the biodiesel blend, which promotes the oxidation of biodiesel blend and thus better combustion of the biodiesel blends takes place. The smoke opacity obtained for diesel and LGBD20 is 69% and 58%, respectively, at full load. Further, the smoke opacity of LGBD20 was decreased by an increase in compression ratios”.

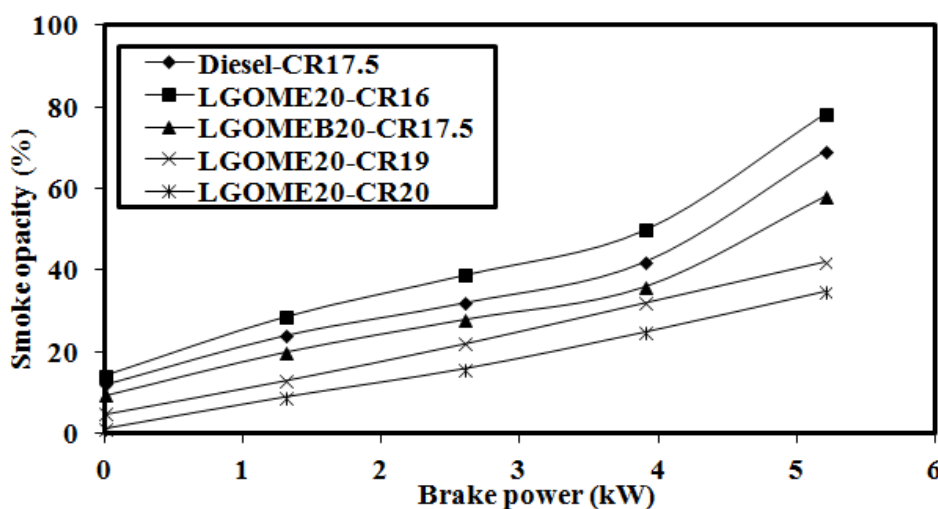


Figure 8: Smoke Opacity Variations with BP.

“The smoke opacity of LGBD20 was decreased by about 24.5% and 36%, respectively, when compared to diesel fuel. This decrease in smoke opacity for LGBD20 at higher compression ratio could be due to the excess oxygen present in the biodiesel blend and by increase in cylinder air temperature during the compression process at higher compression ratios, which leads to more oxidation of biodiesel, which leads to lower smoke emissions, but the smoke opacity of biodiesel blend increases with decrease in compression ratio of 16:1 compared to the standard CR17.5. At full load, the NO_x emission measured for LGBD20 at CR16, CR19 and CR20 is 78%, 42% and 35%, respectively”. The results of smoke emissions are in accordance with the researchers, Jindal *et al.* (2010).

3.3 Combustion Analysis

3.3.1 Cylinder Pressure

The variations of cylinder pressure with respect to crank angle for diesel and LGBD20 at different compression ratios are presented in Fig. 9. It is observed that the combustion pressures are higher than that of diesel fuel at full load for all the higher compression ratios for 20% lemongrass oil biodiesel.

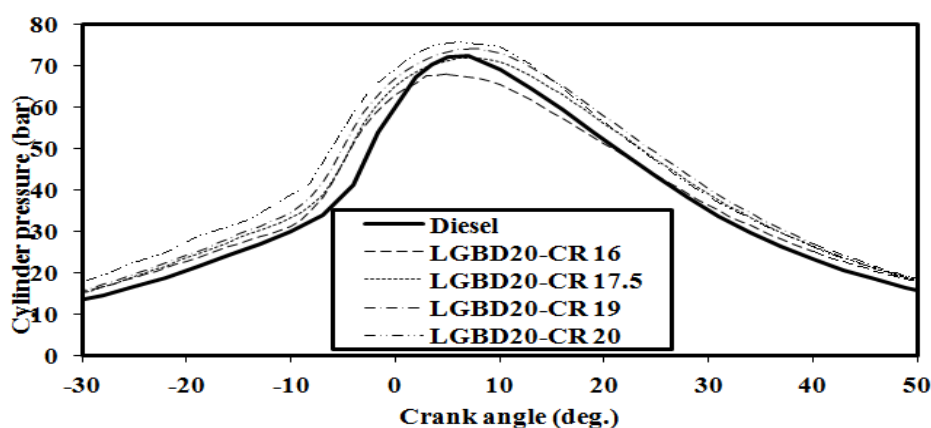


Figure 9: Cylinder Pressure.

“The cylinder peak pressure obtained for LGBD20 with CR20 is higher than other compression ratios with the same blend. This increase in peak pressure may be due to increase in pressure and temperature of air at higher compression ratio and the presence of oxygen in the bio-diesel at full load resulting in complete combustion. At full load, the cylinder pressure for LGBD20 is 67.5 bar, 74.05 bar and 75.7 bar for CR16, CR19 and CR20, respectively, whereas for diesel and LGBD20 it is 72.3 bar and 71.93 bar, respectively, for standard CR17.5”. A similar trend of cylinder pressure was reported by the researchers Muralidharan and Vasudevan, (2011).

3.3.2 Heat Release Rate

“The variation of heat release rate with respect to crank angle for diesel and LGBD20 at different ratios is given in Figure 10. The heat release rate is calculated based on the changes in crank angle variation of the cylinder. At full load, the heat release rate for diesel and LGBD20 with standard is 44.45 J/°CA and 41.5 J/°CA*Corresponding Author.

Respectively with standard compression ratio (17.5:1). The heat release rate obtained at full load for LGBD20 with CR 16, 19 and 20 is 38 J/°CA, 63 J/°CA and 48.8 J/°CA, respectively. The heat release rate obtained for LGBD20 at CR20 is higher when compared with other CRs and diesel. This may be due to increased pressures and temperature of the air during the compression ratios resulting in increased heat release rate”. A similar trend of heat release rate was reported by the researchers Muralidharan and Vasudevan, (2011).

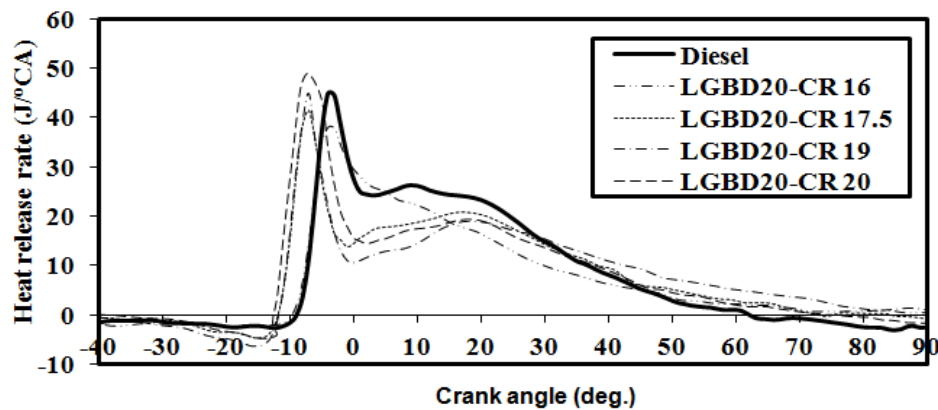


Figure 10: Heat Release Rate.

4. CONCLUSIONS

The performance, emission and combustion characteristics of a direct injection diesel engine fuelled with 20% lemongrass biodiesel blend and diesel with different compression ratios have been investigated and compared with diesel and LGBD20 at full load. From the experimental results the following conclusions were drawn.

- “Brake thermal efficiency of the LGBD20 increases as the compression ratio increases. The maximum brake thermal efficiency is 30.46% for LGBD20 at full load at compression ratio 20, which is 2.62% higher than that of LGBD20 at full and it is comparable with diesel fuel”.
- “The specific fuel consumption decreased with increase in compression ratio. LGBD20 at CR20 gave brake-specific fuel consumption of 0.255 kg/kWh as against 0.25 kg/kWh of diesel at standard CR17.5 and for LGBD20 it is 0.266 at full load”.
- “The hydrocarbon emissions of LGBD20 have been decreased as the compression ratio increases when compared to diesel. The HC emission is 32 ppm at CR20 for LGBD20, whereas for diesel it is 52 ppm at standard CR17.5 at full load”.
- “The CO emissions of the LGBD20 decreases as the compression ratio increases when compared to diesel. The minimum CO emission is 0.09% at CR20 for LGBD20, whereas for diesel it is 0.17% at standard CR17.5 at full load”.
- “The NOx emissions of the LGBD20 increase as the compression ratio increases when compared to diesel. The maximum NOx emission obtained for LGBD20 at CR20 is 2340 ppm, whereas for diesel it is 1950 ppm at standard CR17.5 at full load”.
- “The smoke emissions of the LGBD20 decreases as the compression ratio increases when compared to diesel. The minimum smoke emission obtained for LGBD20 at CR20 is 35%, whereas for diesel it is 69% at standard CR17.5 at full load”.
- “The cylinder pressure and heat release rate for increased LGBD20 increases as the compression ratio increases when compared to diesel. The maximum cylinder pressure and HRR obtained for LGBD20 at CR20 is 74 bar and 48.8 J/°CA, respectively, whereas for diesel it is 72.4 bar and 44.5 J/°CA at standard CR17.5 at full load”.

- “From the above observations, it is found that the performance of the LGBD20 blend is superior when compared with the conventional diesel at higher compression ratio 20. The research also proves that lemongrass oil biodiesel blend can be used instead of diesel fuel in a diesel engine at higher compression ratio 20 with standard injection pressure and injection timing”.

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